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Industrialization of the mirror plate coatings for the Athena mission

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ABSTRACT

In the frame of the development of the Advanced Telescope for High-ENergy Astrophysics (Athena) mission, currently in phase A, ESA is continuing to mature the optics technology and the associated mass production techniques. These efforts are driven by the programmatic and technical requirement of reaching TRL 6 prior to proposing the mission for formal adoption (planned for 2020). A critical part of the current phase A preparation activities is addressing the industrialization of the Silicon Pore Optics mirror plates coating. This include the transfer of the well-established coating processes and techniques, performed at DTU Space, to an industrial scale facility suitable for coating the more than 100,000 mirror plates required for Athena. In this paper, we explain the considerations for the planned coating facility including, requirement specification, equipment and supplier selection, preparing the coating facility for the deposition equipment, designing and fabrication.

Keywords: Athena, Silicon Pore Optics (SPO), Multilayer Deposition, DC Magnetron Sputtering, XRR, X-ray Optics, DTU Space

1. INTRODUCTION

A proper, well-defined, thin-film coating deposited on the mirror plates is critical for the scientific objectives of the Athena mission. The energy range to be covered by Athena stretches from 300 eV to 12 keV [1]. Using mirror plates only composed of Silicon and Silicon Dioxide will not fulfill the throughput requirement for the Athena mission. Introducing a well designed thin-film composed of a high density material and a low density material will increase the throughput of the telescope [2,3,4]. This is presented experimentally for an optimized multilayer composed of Iridium and Boron Carbide irradiated in the energy range from 3-10 keV at fixed grazing incidence of 0.6 degrees [5] and several other thin-film designs [6] measured at the PTB laboratory, BESSY II. The surface roughness of the deposited thin-film shall be lower than 0.5 nm and the interface roughness shall be lower than 0.4 nm. Such results have been shown in [7]. The reflection of X-rays occurs at the interface and the surface of the thin-films and rough surfaces will result in scattering and loss of throughput ultimately reducing the effective area.

In the on-going technology development for the Athena mission, a key objective is demonstrating the scaling up of the SPO production process from R&D levels to the high volumes needed for the flight implementation phase [8]. The direct current (DC) magnetron sputter facility located at DTU Space, Denmark, has been serving as the base thin-film deposition technique for the development of the Athena optics. As a result of the up scaling, the mirror capacity and deposition throughput of the DTU Space sputter unit succumbs and a new deposition unit is required. Furthermore, the shipment of mirror plates from the plate supplier located in the Netherlands and the United Kingdom, to DTU Space located in Denmark and then to cosine located in the Netherlands, becomes time demanding and may result in a reduction of mirror plate cleanliness. Consequently it was decided to centralize the coating facility and the cleaning/stacking facility at cosine [9].

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The coating facility shall be capable of processing 300 mirror plates per day to prove the concept of producing approximately 100,000 flight model plates over the two years flight production period. The production of the mirror plates for the Athena mission is planned to span from 2023 to 2025 [10].

2. SELECTION OF SUPPLIER AND DEPOSITION TECHNIQUE

Selecting a thin-film deposition system, it is necessary to fully understand the purpose of the machine/facility and be compliant with the requirements of the end product [11]. The X-ray reflecting coating requirements for the Athena mission are driven by maximizing the plate throughput and at the same time maintaining a high film quality. The throughput, mainly depending on the deposition method, the chamber capacity and the pumping efficiency, is discussed in section 4.

The timeline for the acquisition and commissioning of the new chamber is presented in figure 1. We present the main steps in the process of designing, purchasing and commissioning an vacuum deposition system. Prior market research, a list of thin-film requirements was established based on the studies being carried out at DTU Space, cosine and European Space Agency (ESA). This list was circulated to several suppliers around the world. A few suppliers provided a quotation of a thin-film deposition system that in principle would meet the requirements established by DTU Space. After the market-research an open tender process was initiated. The production time including factory acceptance testing is approximately 8-9 month. The foreseen calibration of the chamber includes uniformity mapping, determination of deposition rates and more technical aspects presented here. Once the thin-film process performed at DTU Space is fully established in the new coating system, a commissioning is initiated.

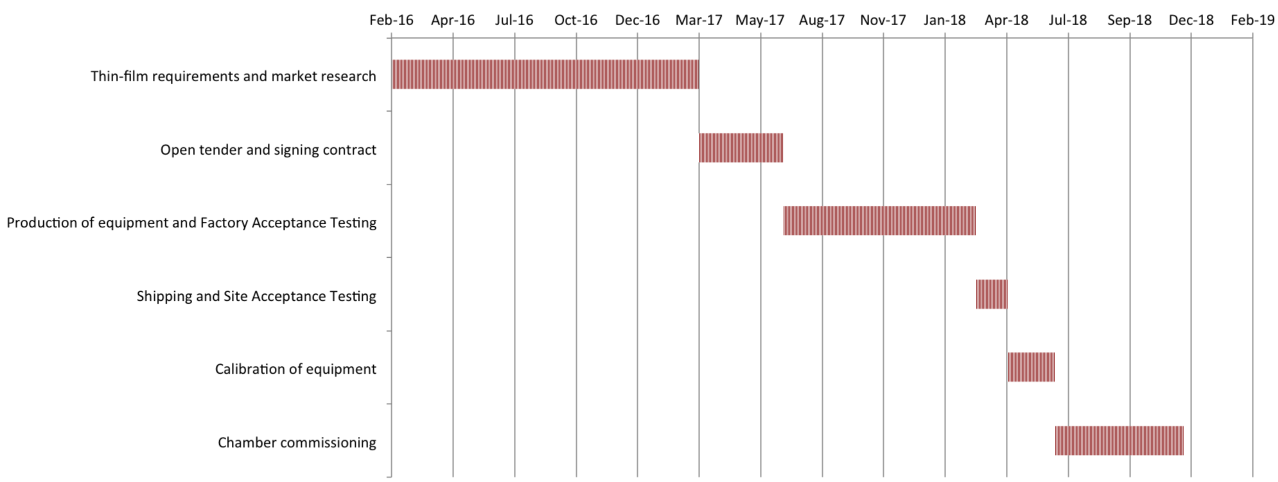

Figure 1: Gantt chart of the acquisition, testing, installation and commissioning process.

2.1 Deposition method and considerations

DC magnetron sputtering has been adopted for depositing reflective coatings on numerous X-ray telescopes, and as such is the method with a good track record for the application at hand. For the Advanced X-ray Astrophysics Facility (AXAF), a detailed study of deposition techniques for X-ray optics was performed [12]. In this study it is presented that magnetron sputtering outperformed evaporative coatings mainly due to higher energetic sputtered atoms resulting in a higher mobility, hence a more dense films. This is confirmed by a study that compares magnetron sputtering to electron-beam evaporation and thermal evaporation [13], where numerous advantages of magnetron sputtering mentioned are, excellent uniformity on large-area substrates, high adhesion of the films to the substrate, ease of sputtering any kind of metal, compound, low cost, high reliability, ease of

process control and high deposition rates. These are extremely important aspects for the thin-film requirements for Athena and DC magnetron sputtering is considered the best approach.
Likewise the optics for the Nuclear Spectroscopic Telescope Array (NuSTAR), the Pt/C and W/Si multilayer thin-films, were successfully deposited using the DC magnetron sputtering technique [14]. Applicability of Ir/B_4C layers to Athena mission showed to fulfill the quality requirements.

2.2 Market research

With the deposition method in place, we contacted several thin-film deposition companies in the world who offers DC magnetron systems. Three different types of systems was presented to us; cluster coater, drum coaters, in-line coaters, from which the cluster tools where disregarded due to the high price and the short-coming on the throughput requirement.
Out of the large group of companies, comparison and trade-off tables provided a clear overview ultimately resulting in a down selection phase. Based on several practical and technical parameters such as, offered system, target-to-substrate flexibility, pump-down time, pre-purchase testing, throughput, cost and more, scores were given to the remaining companies. Von Ardenne scored highest in the overall assessment however company B was given similar scores as. The main difference being the flexibility of performing a pre-purchase test where Von Ardenne was the only company able to perform the test within a reasonable price and time schedule.
Von Ardenne won the tender with DTU Space and is the chosen company for the task at hand.

3. SYSTEM DESIGN

The German company, Von Ardenne, offers a DC magnetrons sputtering drum coater, model BS1200S, which is a custom made device based on the drum coater operating at DTU Space. An illustration of the drum coater can be observed in figure 2. The process chamber will have four process stations, where initially two magnetrons and one inverse sputter etching unit will accommodate three of them. The right hand side image in figure 2 shows a technical drawing of the chamber seen from the top. There are 14 holding spots for the carriers, where the sputter throwing distance can be varied.
For a more efficient and faster pumpdown utilizing a bakeout system is desirable. By heating the chamber surface to >90°C, the moisture sticking to the chamber surface evaporates and is removed from the system through the pumping system.
The back-out unit uses the chamber wall integrated water pipes with an external high temperature control unit to heat the wall with 140°C hot water pressurized to at least 5 bar. The wall will be insulated to prevent heat losses and keep the outside parts cold due to safety issues and to prevent the heating of the surrounding. The bake-out feature will be controlled by system software.

3.1 Flexibility of target-to-substrate distance

The target-to-substrate-distance (TSD) is designed so the mirrors can be placed at three different positions in the carrousel. The TSD available are: 100 mm, 125 mm and 150 mm. The current process at DTU Space is performed at a TSD of ∼155 mm. As a result of a shorter throwing distance, the deposition rate increases due to less scattering of sputtered atoms and changes in the angular distribution of the sputtered atoms [15]. This option may prove significantly important regarding the production time however studies suggest that the film uniformity may worsen due to the angular distribution [16]. The optimal angular distribution of the sputtered atoms and throwing distance will be determined in the foreseen calibration of the deposition system.

3.2 Magnetron design

The planar Small Standard Magnetron (SSM) sputter source is a key-component of Von Ardenne company's SSM type series of rectangular standard single sputter sources operated in DC mode. The magnetrons are vertically arranged at the outer circumference of the process chamber, see figure 2. The flanges of the magnetrons are designed as a door for easy access for maintenance and replacement of targets. Furthermore, it will be possible to install the type of magnetron that is currently practiced at DTU Space. Compared to the existing sputter unit located at DTU Space, which has the full magnetron placed inside the chamber, the contamination exposed surface area is much smaller. This is a great advantage in terms of chamber preparation, pump-down

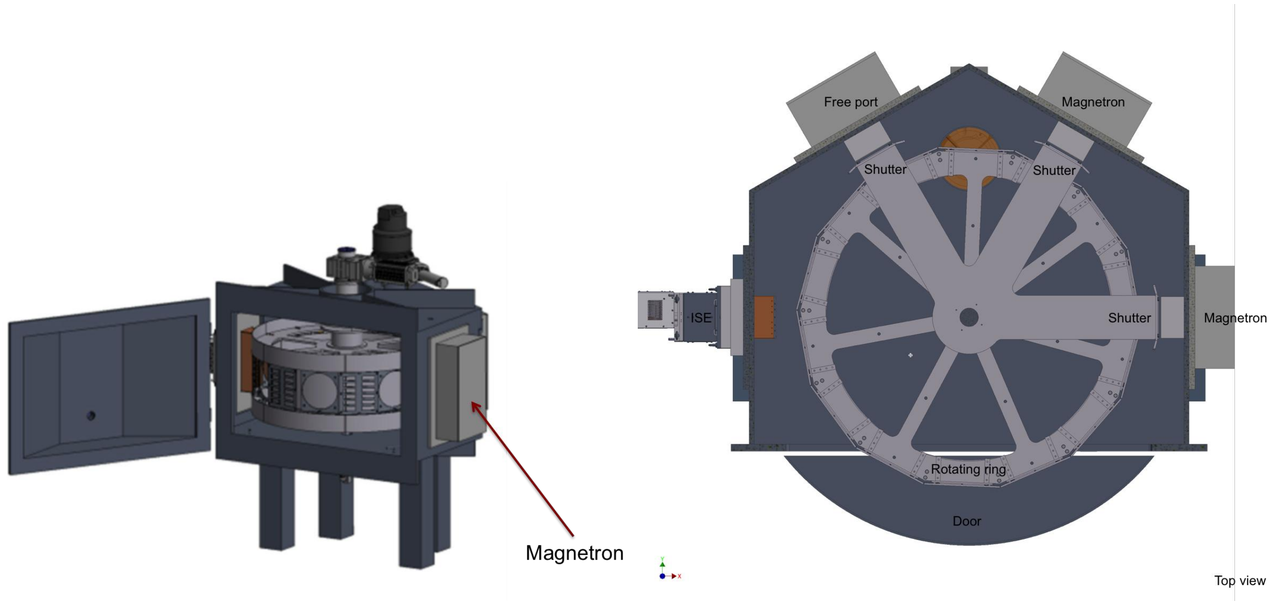

Figure 2: Sketches of the custom designed drum coater, BS1200S. © VON ARDENNE Corporate Archive

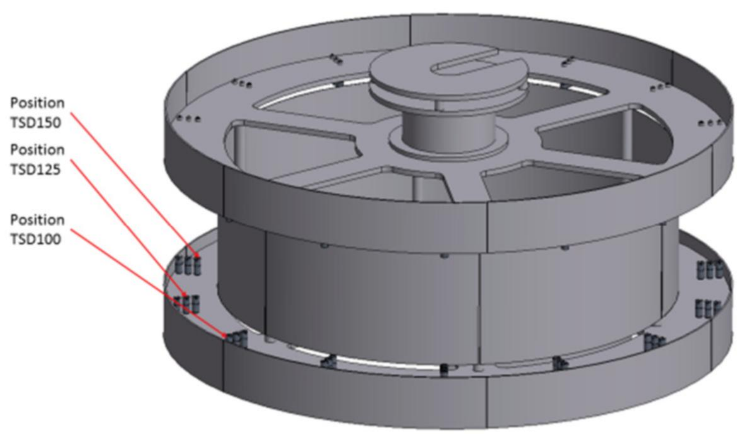

Figure 3: Illustration of the carrier holding carrousel. Three different target-to-substrate distances are applicable. © VON ARDENNE Corporate Archive

time and maintenance time. The SSM source accommodates targets that are 600 mm long and 108 mm wide, which foreseen for Athena will be bonded to a copper backing plate with the targets being divided into tiles. An illustration of a SSM with target material and honey-comb collimation is shown in figure 4.

3.3 Substrate pre-treatment

For a defined surface cleaning/pre-treatment an Inverse Sputter Etcher (ISE) is foreseen for the deposition chamber. The ISE will enable a surface cleaning prior thin-film deposition without breaking vacuum and exposing the surface for atmospheric contamination. Prior thin-film deposition the SPO surface is patterned with photoresist. In between the striped photoresist lines, referred to as the X-ray reflecting surface, is the SiO_2-surface upon where the thin-film will be deposited. This surface contains remnants from the photolithography process, which induces higher roughness in the deposited thin-films. The morphology of the X-ray reflecting surface is shown in [17]. Here it was shown that these photoresist remnants were removable through plasma ashing. The ISE will

Figure 4: Image of an SSM accomodating target material divided into several tiles. A honey comb collimation grid is placed 50 mm from the target surface. © VON ARDENNE Corporate Archive

process Oxygen and Argon gas atoms which are sputtered onto the SPO surface, the Oxygen will remove the organic material and form H_2O, CO_2 and other products. The contamination removal rate will be determined once the deposition system is calibrated. The component will be installed in one of the free process stations. It comes with an RF power supply, matchbox and an RF filter for the DC generator.

4. PRODUCTIVITY ESTIMATE

This section provides a rough estimate of the mirror plate coating production based on the foreseen deposition system described in the latter section. The dimensions may vary slightly in the detailed design phase but is not expected to affect the presented estimate significantly. The productivity estimate includes all aspects of the thin-film deposition process from the point where the plates are mounted into the deposition chamber to the point where they are dismounted. This includes numerous steps that are presented in table 2. The process times are given in minutes and are based on the experience gained on the deposition process performed at DTU Space and verified by the specialists at Von Ardenne.

4.1 Optical design for Athena: Mirror dimensions

The mirror dimension varies as a function of radius in the Athena optics. In the inner radius, the mirrors shall reflect X-rays at the lowest grazing incidence angle with respect to the full optics. To avoid a longer X-ray beam footprint than the mirror length, the mirrors are long, compared to the outer radius where the mirrors are shorter due to the higher grazing incidence. The current Athena baseline design consists of 20 rows with the most updated mirror dimension design presented in table 1. The mounting area is based on the Von Ardenne carrier size assuring uniformity better than 5%. The number of mounted mirrors has been estimated from the mirror dimension and additionally adding 10 mm in both the vertical and horizontal direction between each mirror on the carrier. A sketch of the foreseen mirror placement on the carriers for row 1, 8 and 20 is illustrated in figure 5.

4.2 Process steps, assumptions and calculations

Process step 1, 3, 4, 5 and 7 presented in table 2, is independent of the number of mirrors and the mirror dimension, with the most time-consuming step being reaching the base-pressure. Process step 2 and 8 depends on the number of mirrors that can be mounted on the carrier. The mounting of the samples onto the carrier is currently performed by hand. For the flight production an automated handling of the plates is foreseen and this requires a technique to move a plate and place it on the carrier. For the calculation, 15 seconds have been appointed for placing a single mirror on the carrier and 30 seconds for placing the carrier inside the drum. Obviously, by purchasing a second set of carriers it enables us to reduce the mirror-to-carrier mounting time, as this can be done while the previous batch is being processed.

The thin-film deposition time mainly depends on the thin-film design, and the pre-sputtering time of five minutes per target becomes less significant in the calculations. The pre-sputtering removes any oxidized layer

Row number	Mirror Dimension (mm)		Mounting area on carrier (mm)		Number of mounted mirrors in the horizontal and vertical direction		Number of mirrors per carrier	Total mirrors per batch
-	Width	Length	Width	Length	Vertical	Horizontal	-	-
1	37,1	101,5	310	260	6	2	12	168
2	50,2	83,4	310	260	5	2	10	140
3	49,8	70,8	310	260	5	3	15	210
4	49,6	61,5	310	260	5	3	15	210
5	89,4	54,3	310	260	3	4	12	168
6	82,5	48,7	310	260	3	4	12	168
7	77,6	44,1	310	260	3	4	12	168
8	86,9	40,3	310	260	3	5	15	210
9	82,1	37,1	310	260	3	5	15	210
10	90,2	34,4	310	260	3	5	15	210
11	85,5	32,0	310	260	3	6	18	252
12	92,8	30,0	310	260	3	6	18	252
13	88,3	28,2	310	260	3	6	18	252
14	94,8	26,6	310	260	2	7	14	196
15	90,6	25,2	310	260	3	7	21	294
16	87,1	23,9	310	260	3	7	21	294
17	92,5	22,8	310	260	3	7	21	294
18	89,1	21,7	310	260	3	8	24	336
19	94,1	20,8	310	260	2	8	16	224
20	90,9	19,9	310	260	3	8	24	336

Table 1: Mirror dimensions for each row of the current design for the Athena optics. The total number of mirrors per batch is shown based on the Von Ardenne carrier design. The total number of carriers, which define a batch is 14.

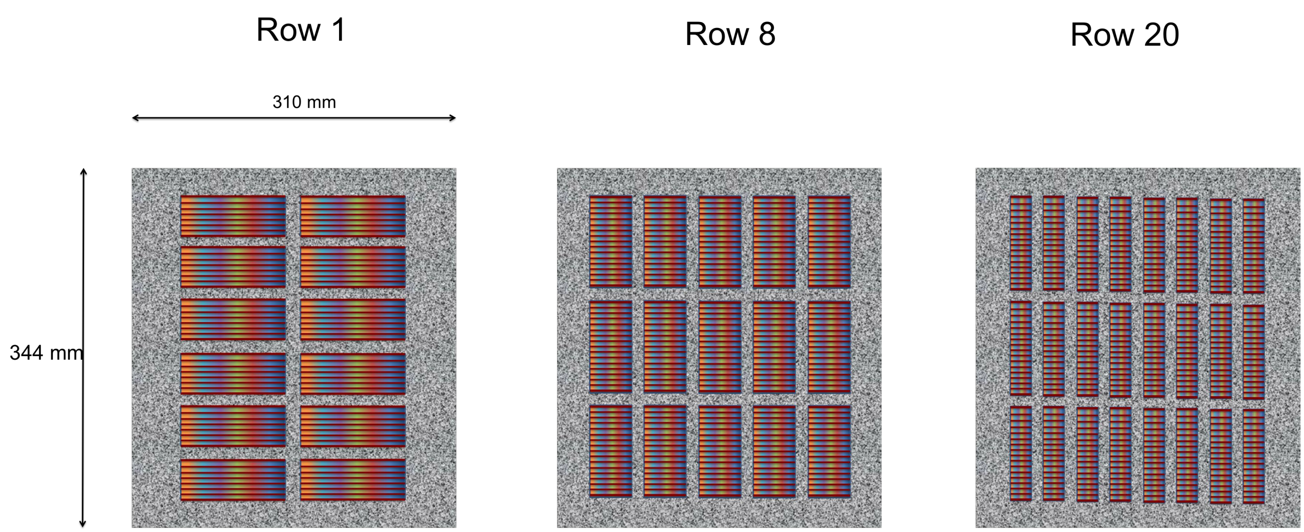

Figure 5: Foreseen mirror plate configuration on the Von Ardenne carrier design.

on the target surface for a stable and clean sputtering process. The pre-sputtering of 5 minutes is sufficient to remove contamination from the target surface. Prior and during the pre-sputtering, shutters, which are metallic plates will be moved into the sputtering path from the target to the substrate, hence collecting the contaminated material. This will ensure a clean X-ray reflecting coating.

The single bilayer used for the throughput calculation presented in table 3, represents the optimized Athena baseline with a bottom layer of 10.0 nm Ir and a top-layer of 8.0 nm B_4C. The proposed thin-film multilayer design consists of single bilayers and linear graded multilayer thinfilms and the estimated productivity is shown in table 4. This optimized multilayer coating design is presented in [18] and would improve the effective area at 6 keV with approximately 46% compared to the single bilayer design. The last productivity table presented,

Process step	Description	Process time per batch (min)	Comment
1	**Chamber preparation**	**19**	
1.1	Removal of dust particles	15	Nitrogen blow/Vacuum clean
1.2	Inspection of targets	2	Visual
1.3	Inspection of magnetrons	2	Visual + electrical parameters
2	**Mounting**	**49**	
2.1	Samples on carriers	42	15 seconds based on current mounting method
2.2	Carriers in chamber	7	30 seconds per carrier
3	**Pre-pump down preparation**	**1**	
3.1	Cleaning surfaces with IPA	1	Remove particles
4	**Pump-down**	**240**	
4.1	Reach base-pressure	240	Less than 2x10^-6 Torr including bake-out
5	**Substrate pre-treatment**	**10**	
5.1	Sputter etching	10	Removal of organic material on reflective surface
6	**Thin-film deposition**	**107**	
6.1	Reach working gas pressure	2	Order of 3x10^-3 Torr
6.2	Pre-sputtering	10	5 minutes per material
6.3	Deposition time	95	Based on deposition rate of DTU Space system
7	**Pump-up**	**10**	
7.1	Reach atmosperic pressure	10	Venting with Nitrogen
8	**Dismounting**	**49**	
8.1	Carriers in chamber	7	30 seconds per carrier
8.2	Samples on carriers	42	15 seconds based on current mounting method
Total time		**485**	

Table 2: Thin-film deposition process steps. This is a specific case for the baseline coating consisting of a single bilayer, row 1, for Athena.

table 5, is for a thin-film design only consisting of a single layer of Iridium. This will reduce the effective area of the telescope in the lower energy spectrum (<5 keV), which is otherwise boosted by the lower density material.

The applied dynamic deposition rate (DDR) for Ir and B_4C is 2.1 nm·m/min and 0.53 nm·m/min, respectively. These numbers are based on the derived power density of 3.1 W/cm^2 for Ir and a power density of 5.17 W/cm^2 for B_4C for the targets installed in the DTU Space deposition chamber. These rates emanate from a throwing distance of 155 mm, including honey-comb collimation installed in the TSD and a working gas pressure of 2.5 mTorr. Similar or better DDR's are foreseen from the Von Ardenne chamber.
The coating length of the Von Ardenne drum coater is 4774 mm corresponding to a full rotation. One full rotation will result in a single layer of either Ir or B_4C and is thereby the nature of the calculated deposition times, given in table 3-5. In the case of the multilayer design, table 4, the total thin-film thickness of each material is presented.

It is unlikely that downtime can be avoided completely due to magnetron maintenance and other unforeseen failures, which is reflecting the yield of 85 % in the tables. With the foreseen Von Ardenne magnetrons this may be not be the case as their magnetrons are designed from scratch to endure much more stringent 24/7 coating conditions. However to provide a margin in the estimation the yield of 85 % is included in the calculations.
The total coating time per ring is given by equation 1.

$$\text{Total coating time per ring} = \frac{\text{Actual number of plates per ring}}{\text{Total mirrors per batch}}(\text{Preparation time} + \text{Deposition time per batch}) \tag{1}$$

The total coating time for all 20 rows given in days are based on a continuous flow of mirror production, implying that when one batch is completed the next is processed. This will demand operators engaged 24/7, which is currently not planned for the Athena flight production.
As a result of this productivity estimate, performing the thin-film deposition of the latter mentioned designs, having a second deposition chamber will be key to ensure a successful flight production of the Athena optics. Unforeseen down-time can occur do to component failures resulting in replacements with long lead times.

Row	Total thin-film thickness (nm)		Deposition time per batch (min)	Preparation time (min)	Number of mirror modules	Number of plates per ring	Yield (%)	Actual number of plates per ring	Total coating time per ring (h)
-	Ir	B_4C	-	-	-	-	-	-	-
1	10.0	8.0	95	390	120	4200	85	4941	242
2	10.0	8.0	95	376	120	4200	85	4941	282
3	10.0	8.0	95	411	144	5040	85	5929	244
4	10.0	8.0	95	411	168	5880	85	6918	278
5	10.0	8.0	95	390	120	4200	85	4941	242
6	10.0	8.0	95	390	144	5040	85	5929	291
7	10.0	8.0	95	390	168	5880	85	6918	339
8	10.0	8.0	95	411	168	5880	85	6918	278
9	10.0	8.0	95	411	192	6720	85	7906	320
10	10.0	8.0	95	411	192	6720	85	7906	320
11	10.0	8.0	95	432	216	7560	85	8894	316
12	10.0	8.0	95	432	216	7560	85	8894	316
13	10.0	8.0	95	432	240	8400	85	9882	351
14	10.0	8.0	95	404	240	8400	85	9882	424
15	10.0	8.0	95	453	264	9240	85	10871	338
16	10.0	8.0	95	453	288	10080	85	11859	374
17	10.0	8.0	95	453	288	10080	85	11859	374
18	10.0	8.0	95	474	316	11060	85	13012	370
19	10.0	8.0	95	418	312	10920	85	12847	496
20	10.0	8.0	95	474	336	11760	85	13835	398
Total	-	-	-	-	**4252**	**148820**	-	**175082**	**275 days**

Table 3: Productivity estimate based on the single bilayer baseline thin-film design.

Row	Total thin-film thickness (nm)		Deposition time per batch (min)	Preparation time (min)	Number of mirror modules	Number of plates per ring	Yield (%)	Actual number of plates per ring	Total coating time per ring (h)
-	Ir	B_4C	-	-	-	-	-	-	-
1	10.0	8.0	95	390	120	4200	85	4941	242
2	10.0	8.0	95	376	120	4200	85	4941	282
3	10.0	8.0	95	411	144	5040	85	5929	244
4	10.0	8.0	95	411	168	5880	85	6918	278
5	15.4	16.1	180	390	120	4200	85	4941	285
6	36.0	47.0	505	390	144	5040	85	5929	537
7	35.0	45.4	489	390	168	5880	85	6918	615
8	47.5	64.3	687	411	168	5880	85	6918	604
9	46.0	62.0	663	411	192	6720	85	7906	680
10	41.5	55.3	593	411	192	6720	85	7906	636
11	41.5	55.3	593	432	216	7560	85	8894	615
12	40.0	53.0	568	432	216	7560	85	8894	600
13	37.0	48.5	521	432	240	8400	85	9882	635
14	35.5	46.3	498	404	240	8400	85	9882	767
15	35.5	46.3	498	453	264	9240	85	10871	586
16	34.0	44.0	474	453	288	10080	85	11859	633
17	32.5	41.8	450	453	288	10080	85	11859	617
18	32.5	41.8	450	474	316	11060	85	13012	601
19	32.5	41.8	450	418	312	10920	85	12847	840
20	32.5	41.8	450	474	336	11760	85	13835	647
Total	-	-	-	-	**4252**	**148820**	-	**175082**	**456 days**

Table 4: Productivity estimate based on the optimized multilayer thin-film design.

Row	Total thin-film thickness (nm)	Deposition time per batch (min)	Preparation time (min)	Number of mirror modules	Number of plates per ring	Yield (%)	Actual number of plates per ring	Total coating time per ring (h)
-	Ir	-	-	-	-	-	-	-
1	10.0	23	385	120	4200	85	4941	204
2	10.0	23	371	120	4200	85	4941	236
3	10.0	23	406	144	5040	85	5929	207
4	10.0	23	406	168	5880	85	6918	236
5	10.0	23	385	120	4200	85	4941	204
6	10.0	23	385	144	5040	85	5929	245
7	10.0	23	385	168	5880	85	6918	285
8	10.0	23	406	168	5880	85	6918	236
9	10.0	23	406	192	6720	85	7906	272
10	10.0	23	406	192	6720	85	7906	272
11	10.0	23	427	216	7560	85	8894	270
12	10.0	23	427	216	7560	85	8894	270
13	10.0	23	427	240	8400	85	9882	300
14	10.0	23	399	240	8400	85	9882	358
15	10.0	23	448	264	9240	85	10871	290
16	10.0	23	448	288	10080	85	11859	322
17	10.0	23	448	288	10080	85	11859	322
18	10.0	23	469	316	11060	85	13012	320
19	10.0	23	413	312	10920	85	12847	421
20	10.0	23	469	336	11760	85	13835	344
Total	**-**	**-**	**-**	**4252**	**148820**	**-**	**175082**	**234 days**

Table 5: Productivity estimate based on a single Iridium thin-film layer.

5. DESIGN AND PREPARATION OF THE FACILITY

The sputtering unit will be installed, calibrated and commissioned at cosine in 2018. Several preparations shall be considered such as, space for the deposition system, compatibility with the cleanroom standard, physical moving through doors, electricity/water/gas connections and process flow compatibility.

There are currently five clean rooms located at cosine, see floor plan in figure 6. The most compatible cleanroom for installing the deposition system, in terms of the later mentioned items, is cleanroom 2, which is directly adjacent to technical rooms. This is shown in figure 6. Due to the maintenance of the deposition system, it is favorable to install most of the parts in a gray room connecting the door facing side of the system with cleanroom 2, as illustrated in figure 7. The foreseen flow of the SPO production is given below:

Cleanroom 1 Plates are received and inspected

Cleanroom 2 Plates are plasma cleaned, deposited with thinfilm materials and lifted

Cleanroom 3 Plates are cleaned and stacked

Cleanroom 4 Stacks are inspected and tested

Cleanroom 5 Reserved

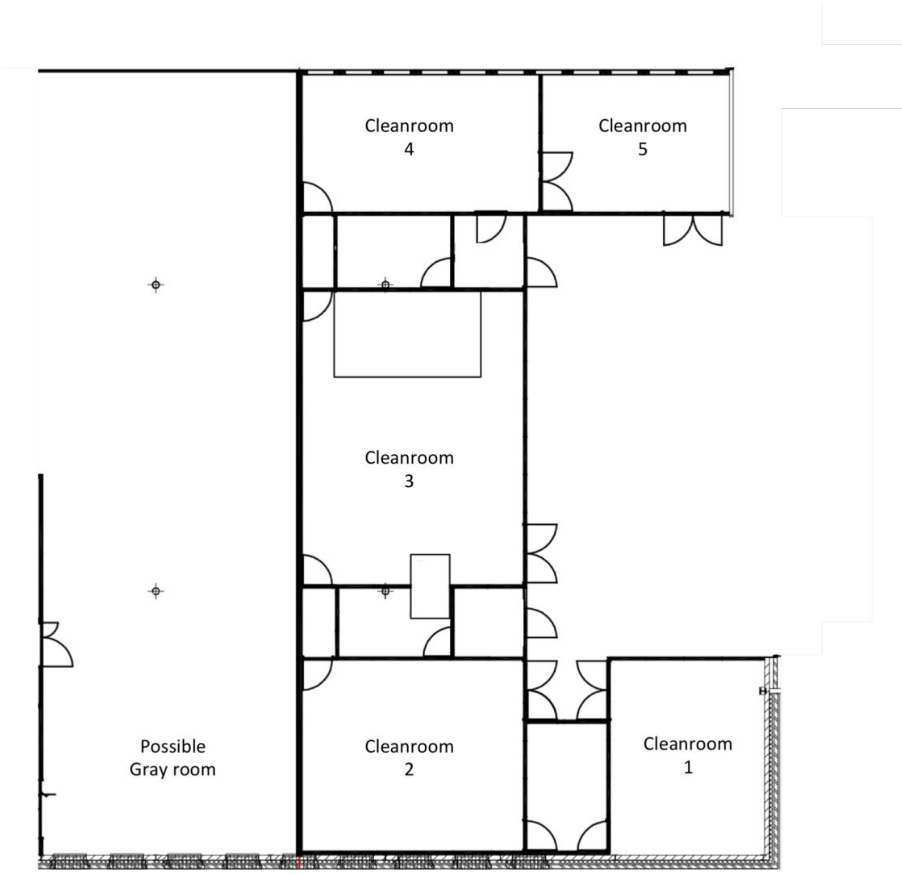

Figure 6: Floor plan of the cleanrooms located at cosine.

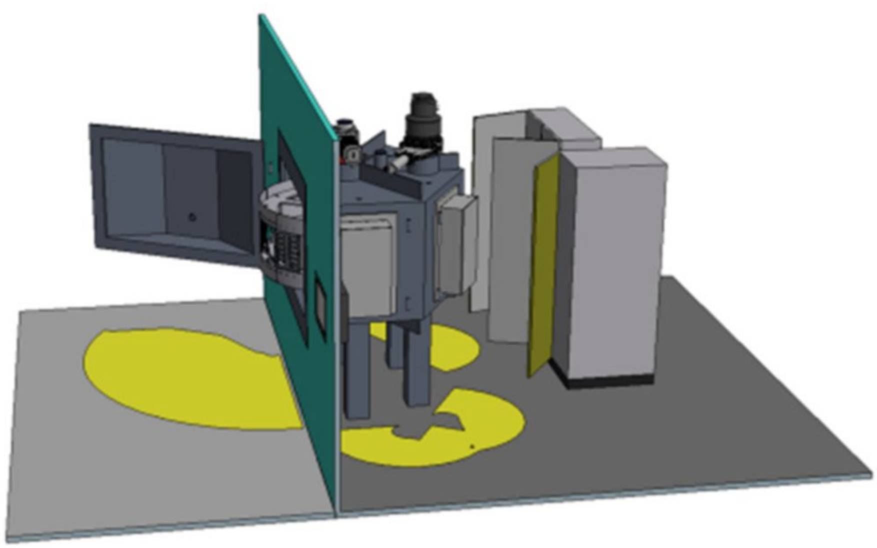

Figure 7: Illustration of the BS1200S installed in a gray-room with access to the drum from a cleanroom. © VON ARDENNE Corporate Archive

6. PRODUCT ACCEPTANCE TESTING

Once the deposition system is completed, a factory acceptance test (FAT) will be carried out at Von Ardenne to demonstrate the compliancy with the requirements for the Athena thin-films. The FAT is designed by DTU Space based on investigating the thin-film parameter space within the current designs for the Athena mission. The test will consist of 12 different thin-films, a blend of single layers and multilayers of Ir and B_4C, shown in table 6. The several thicknesses will provide information about the deposition rate, the stress induced by the thin-film, the surface and interface roughness, the thickness deviation and the density of the thin-films. These are all parameters that are well known in the deposition process performed at DTU Space and can be directly compared. Furthermore the same process parameters (pressure, target-substrate distance, power density and collimation) will be used. The thin-films will be deposited on super polished silicon substrates with a surface roughness ∼0.25 nm provided by International Wafer Service.

The characterization of the samples will be carried out at DTU Space with several characterization tools, such as 8.047 keV X-ray reflectometry (XRR), Atomic Force Microscopy (AFM), Stylus profilometer and X-ray Photoelectron Spectroscopy (XPS), and at a synchrotron facility providing low energy XRR setups. With the XRR we will derive the thickness, interface/surface roughness and the composition. The AFM will be used to measure the surface roughness at confined areas of the samples. The stress level induced by the thin-film is measured with a Stylus profilometer and the density can be modeled with XPS measurements.

The thickness deviation will be determined through a Gauge R&R method [19].

Sample no.	Material	Thickness (nm)	Maximum thickness deviation (%)
1	Boron Carbide	5.0	≤±3
2	Boron Carbide	8.0	≤±3
3	Boron Carbide	20.0	≤±3
4	Boron Carbide	30.0	≤±3
5	Iridium	5.0	≤±3
6	Iridium	10.0	≤±3
7	Iridium	20.0	≤±3
8	Iridium	30.0	≤±3
9	Boron Carbide	8.0	≤±3
	Iridium	10.0	≤±3
10	Boron Carbide (top)	1.2	≤±5
	Iridium	1.8	≤±5
	Boron Carbide	1.2	≤±5
	Iridium	1.8	≤±5
	Boron Carbide	1.2	≤±5
	Iridium	1.8	≤±5
	Boron Carbide	1.2	≤±5
	Iridium	1.8	≤±5
	Boron Carbide	1.2	≤±5
	Iridium	1.8	≤±5
	Boron Carbide	1.2	≤±5
	Iridium	1.8	≤±5
	Boron Carbide	1.2	≤±5
	Iridium	1.8	≤±5
	Boron Carbide	1.2	≤±5
	Iridium	1.8	≤±5
	Boron Carbide	1.2	≤±5
	Iridium	1.8	≤±5
	Boron Carbide	1.2	≤±5
	Iridium (bottom)	1.8	≤±5
11	Boron Carbide (top)	2.4	≤±5
	Iridium	3.6	≤±5
	Boron Carbide	2.4	≤±5
	Iridium	3.6	≤±5
	Boron Carbide	2.4	≤±5
	Iridium	3.6	≤±5
	Boron Carbide	2.4	≤±5
	Iridium	3.6	≤±5
	Boron Carbide	2.4	≤±5
	Iridium	3.6	≤±5
	Boron Carbide	2.4	≤±5
	Iridium	3.6	≤±5
	Boron Carbide	2.4	≤±5
	Iridium	3.6	≤±5
	Boron Carbide	2.4	≤±5
	Iridium	3.6	≤±5
	Boron Carbide	2.4	≤±5
	Iridium	3.6	≤±5
	Boron Carbide	2.4	≤±5
	Iridium (bottom)	3.6	≤±5
12	Boron Carbide (top)	4.0	≤±3
	Iridium	6.0	≤±3
	Boron Carbide	4.0	≤±3
	Iridium	6.0	≤±3
	Boron Carbide	4.0	≤±3
	Iridium	6.0	≤±3
	Boron Carbide	4.0	≤±3
	Iridium	6.0	≤±3
	Boron Carbide	4.0	≤±3
	Iridium	6.0	≤±3
	Boron Carbide	4.0	≤±3
	Iridium	6.0	≤±3
	Boron Carbide	4.0	≤±3
	Iridium	6.0	≤±3
	Boron Carbide	4.0	≤±3
	Iridium	6.0	≤±3
	Boron Carbide	4.0	≤±3
	Iridium	6.0	≤±3
	Boron Carbide	4.0	≤±3
	Iridium (bottom)	6.0	≤±3

Table 6: Thin-film designs foreseen to be produced as part of the acceptance testing.

7. FORESEEN CALIBRATION OF DEPOSITION CHAMBER

An important aspect of commissioning a new deposition chamber is to map the thin-film uniformity as a function of mirror position along the length of the magnetron [20]. Due to race tracks, magnetic field topography and geometric factors, the atom flux emitted along the length of the target varies, with the maximum atom flux being emitted from the center of the target. The procedure for mapping the uniformity is still under development however the main principle will be to place multiple mirror substrates on positions as shown in figure 8 for a single layer film deposition, following a thickness measurement. From an expected thickness variation along the target length, the film uniformity given as a function of mirror position in the chamber, will serve as base for the masking design. Following the uniformity mapping we will produce a mask and place it in the path between the target and the mirror plates resulting in a better thin-film uniformity along the target length.

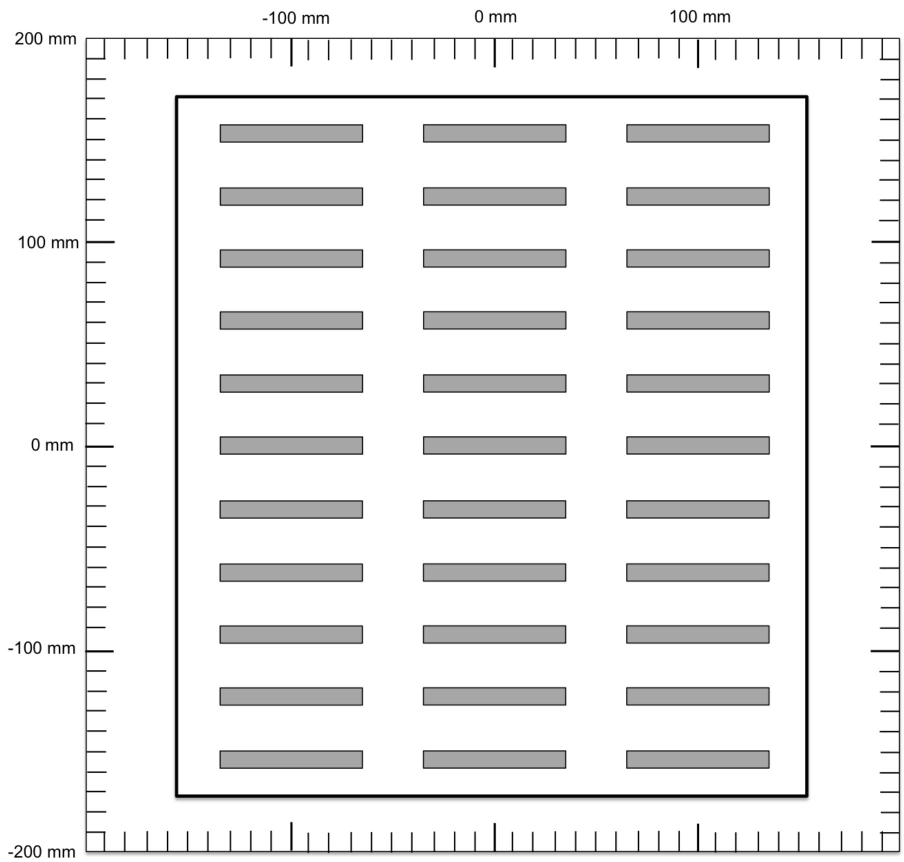

Figure 8: Foreseen mirror placement on the Von Ardenne carrier. The mirrors will cover the mounting area ensuring a uniformity better than 5%.

8. SUMMARY

We reported on the most recent updates of the industrialization of the mirror plate coatings for the Athena mission. A thorough market research was performed, based on a list of thin-film requirements established by ESA, cosine and DTU Space. DC-magnetron sputtering has been selected as the thin-film deposition method due to the excellent record within X-ray optics.

We have through a public tender selected a supplier, Von Ardenne, who met the requirements and pursued the project actively. The drum coater BS1200S was designed based on the existing drum coater at DTU Space and provides the user a great flexibility in the sputtering process.

Based on the BS1200S carrier and magnetron dimensions we produced a productivity estimate of the most recent

optics design for Athena. Three different productivity estimates are presented, one for a single bilayer design, one for an optimized multilayer design boosting the effective area of the telescope at 6 keV and one for a single layer design, which is the minimum requirement for the Athena mission.
We presented the visual and technical layout of the future thin-film deposition facility for the Athena mission, which will be located in Warmond, The Netherlands.
The product acceptance testing will be carried out at Von Ardenne (FAT) and again at cosine (SAT) to verify the systems compliancy with the thin-film requirements. A full description of the testing and the methods for characterizing the results has been presented.
Ultimately, a foreseen calibration of the deposition chamber is given, once the SAT has been performed. This shall lead to a commissioning of the thin-film facility.

9. ACKNOWLEDGEMENT

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